Parameterization of Clouds and Convection in the NCEP Global Model

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Progress Report

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Title of Research Grant: Parameterization of Clouds and Convection in the NCEP Global Model

1 Scientific Goals

The purpose of the ARM Program is to improve the treatment of radiation and clouds in the models used to predict future climate, particularly the General Circulation Models (GCMs). We will improve the representation of clouds (and thereby radiation) in the National Centers for Environmental Prediction (NCEP) global numerical weather prediction (NWP) model using ARM observations, the 2D University of Utah Cloud Resolving Model (UU CRM), a single-column model (SCM) derived from the NCEP global model, and the NCEP global model itself.

We have run the UU CRM and the NCEP SCM using ARM analyses for the 29-day Summer 1997 SCM IOP at the Southern Great Plains (SGP) site. We will use ARM measurements to evaluate these model results, with a focus on the representations of clouds, specifically, cumulonimbus and cirrus clouds, which are the most important cloud types at the SGP during the summer in terms of radiative impact. Both cloud types affect radiation directly, as well as indirectly by modifying the atmospheric state (and thereby future cloud formation) through their microphysical, radiative, turbulent, and convective processes.

We will focus on the following two scientific issues: (1) The occurrence (time and intensity) of cumulonimbus clouds over land during the summer. Occurrence is affected by the diurnal cycle over land, and other interactions with the boundary layer. (2) The formation and decay of mid-latitude summer cirrus clouds, including their formation by cumulonimbus clouds. In particular: How much microphysical complexity is required to adequately represent cirrus clouds in GCMs?

We will analyze the CRM results in detail to better understand how to improve the NCEP global model's representation of these cloud types. We will then make changes/improvements to the NCEP cloud parameterizations. Finally, we will test the modified parameterizations in the NCEP SCM and in the NCEP global NWP model, in a collaborative effort with NCEP's Environmental Modeling Center.

We will also compare the predictions by NCEP's global model of clouds and their radiative impacts at the ARM sites (SGP, NSA, and TWP) to observations for several months.

2 Summary of Significant Accomplishments During the Past Year

- Tested a GCM cloud fraction parameterization derived from cloud resolving model (CRM) results using retrievals of LWC profiles based on cloud radar and microwave radiometer measurements. Investigated the impact of the observational uncertainties involved due to sampling by sampling the results of CRM simulations in the same manner. We found that due to the mesoscale variability of LWC, the LWC must be time-averaged for at least 3 hours in order to obtain a sufficiently accurate estimate of its large-scale value for use in the cloud fraction parameterization.

- Completed a model intercomparison project that evaluated cloud resolving models and single-column models by testing their ability to determine the large-scale statistics of precipitating convective cloud systems during a multiday period of TOGA COARE (Tropical Oceans Global Atmosphere Coupled Ocean-Atmosphere Response Experiment). There are statistically significant differences between the consensus SCM and consensus CRM results for several quantities. For these quantities, the CRM results are closer to observations (when available) than are the SCM results.

- Initiated a similar model intercomparison project based on the Summer 1997 SCM IOP at the SGP site. The time-averaged CRM results for periods of deep convection show consistenly smaller biases of time-averaged temperature and water vapor than do the SCM results using traditional forcing methods. The time-averaged CRM cloud fraction profiles are in reasonable agreement with the observations from the cloud radar, while many of the SCM profiles are not. The CRM and SCM mass flux profiles show significant differences in the lower troposphere.

- We compared thin cirrus statistics (frequency distributions of IWP, IWC, layer thickness, and mid-cloud height) obtained from the the UCLA-CSU CRM's simulation for the Summer 1997 SCM IOP at the SGP site to Mace's statistics (which are for an entire year). This demonstrates that CRM results can be sampled in a way that allows direct comparison to ARM cirrus cloud property retrievals. This allows an unprecedented evaluation of the CRM's representation of cirrus cloud physics.

- We have obtained and compared the cloud fraction profiles for the entire Summer 1997 SCM IOP as observed by the MMCR, simulated by the UCLA-CSU CRM, and simulated by the NCEP SCM.

3 Progress and Accomplishments Under the Current Grant

3.1 Using ARM Measurements to Test a Cloud Fraction Parameterization

We have been comparing observed boundary layer cloud fractions with a cloud fraction parameterization developed by Xu and Randall (1996, hereafter XR). XR proposed to relate the large-scale cloud fraction to the large-scale cloud water mixing ratio and relative humidity. By "large- scale" we refer to space and time scales resolved by a global NWP model or a global climate model. A large-scale quantity typically represents a spatial average over an area of 250 km by 250 km.

We have used both CRM results and observations to examine various aspects of this parameterization. The observations, collected during ASTEX, include relative humidity (obtained from 3-hourly radiosonde soundings), and liquid water content and cloud fraction (obtained from millimeter cloud radar measurements and cloud water content retrievals).

(Note that this type of study is difficult to perform using ARM data from the SGP due to contamination of boundary layer cloud echoes by insects.)

Because of the inherent limitations/problems associated with the ASTEX observations (e.g., relative humidity biases, data sampling, missing data etc.), we have augmented the observational study by also applying XR to a CRM simulated data set of similar cloud types (Krueger et al. 1995). A particularly difficult question to answer using observations alone, for example, is determining whether or not the differences between the observational estimates of the large-scale liquid water content, relative humidity, and cloud fraction and their actual values are significant? That is, do they affect our evaluation of XRs parameterization of cloud fraction? By sampling the model data as if they were a detailed set of observations, we tested this hypothesis. Our results indicate that, for the types of clouds observed during ASTEX, the mesoscale variability of the liquid water content is greater than that of the relative humidity. We are now applying this result to the observations by increasing the temporal and spatial (i.e., vertical) averaging of the retrieved input liquid water content profiles.

3.2 Intercomparisons of multi-day simulations of convection

Large-scale modelers at NCEP and ECMWF have identified the following processes as two of those most in need of improved representation in their parameterizations of precipitating convective cloud systems.

- The occurrence (frequency and intensity) of deep convection. This includes the diurnal cycle over land, and other interactions with the boundary layer.
- The production of upper tropospheric stratiform clouds by deep convection. A related issue: How much microphysical complexity is required in GCMs?

The importance of these processes has influenced which aspects of cloud parameterization testing and improvement to focus on, and has also motivated us to shift the emphasis of our research from oceanic precipitating convective cloud systems (i.e., TOGA COARE) to continental ones (i.e., ARM SGP).

3.2.1 GCSS WG 4: Case 2, TOGA COARE

We have nearly completed the GCSS (GEWEX Cloud System Study) WG 4 model intercomparison study based on this case and will shortly submit a paper that describes the results (Krueger et al. 2000). The case is based on a 6-day period encompassing several episodes of deep convection observed in TOGA COARE in the Intensive Flux Array and was used to test the ability of CRMs and SCMs to predict large-scale statistics of precipitating convective cloud systems. Eight models of each type participated.

The main results of this study were summarized in last year's proposal. Since then we have compiled consensus CRM and SCM results and used statistical tests to identify what aspects of the two model types are significantly different.

For this case, the CRMs in general matched observations more closely than did the SCMs. The SCMs had significantly lower water vapor paths, lower cloud water and cloud ice paths, lower albedo, greater solar radiative heating, and greater upper tropospheric cloud fraction than the CRMs.

3.2.2 GCSS WG 4 and ARM SCM WG: Case 3, SGP CART

This case of continental deep convection is based on intensive measurements taken at the ARM SGP site during the Summer 1997 SCM IOP. The millimeter cloud radar (MMCR) was operational during this time and has provided profiles of cloud fraction. In addition, Jay Mace has performed retrievals of thin cirrus cloud properties for this period.

Case 3 is being done in collaboration with GCSS WG 4. WG 4 selected 3 4- or 5-day subcases for CRMs to simulate. Participation by CRMs (mostly unaffiliated with ARM) and SCMs has been excellent. Seven CRMs (two with both 2D and 3D simulations) and seven SCMs have submitted results. See Xu et al. (2000) for further details.

The results strongly confirm what Case 2 suggested: (1) The CRM results for periods of deep convection show consistenly smaller biases of temperature and water vapor than do the SCM results using the same large-scale advective forcing methods. (2) The time-averaged CRM cloud fraction profiles are in reasonable agreement with the observations from the cloud radar, while many of the SCM profiles are not. (3) The CRM and SCM mass flux profiles show significant differences in the lower troposphere. (4) The CRM surface precipitation rates are better correlated with the observations than those from SCMs.

The SCM cloud fractions are typically too large in the upper troposphere. This motivated us to begin a study of cirrus clouds by comparing the properties of those retrieved by Jay Mace to those simulated by the CSU CRM (see below).

In addition, we found that the convection (and associated clouds) produced in the CRM simulations is sometimes delayed by a few hours relative to observations. The delayed convection is usually more intense than observed as well. This motivated us to start a study of the interactions of deep cumulus convection and the boundary layer based on CRM results and observations (see below).

3.3 Using ARM Measurements to Evaluate Model Results

The accomplishments described below were largely carried out during the past two months by Yali Luo, my new graduate student, who passed her qualifying exams with distinction in mid-May.

3.3.1 Cirrus Cloud Statistics: Simulated Compared to Observed

Mace et al. (2000) used cloud radar and IR spectral radiometer measurements to retrieve 3-minute-averaged thin cirrus properties over the ARM SGP site when there were no lower clouds. We sampled results (provided by Kuan-Man Xu) of a 29-day simulation by the UCLA-CSU CRM of the Summer 1997 SCM IOP at the ARM Southern Great Plains site at 8 grid columns (64 km apart) every 5 minutes using the same criteria.

We compared the CRM's thin cirrus statistics (frequency distributions of IWP, IWC, layer thickness, and mid-cloud height) to Mace's statistics (which are for an entire year). The comparisons are shown in Fig. 1. Note that the cloud radar's vertical grid interval is about 100 m, while the CRM's is about 800 m. These results were presented by Jay Mace at the GCSS WG 2/3 (Cirrus/Frontal Clouds) Workshop (July 16-18, 2000).

This study demonstrates that CRM results can be sampled in a way that allows direct comparison to Mace's cirrus cloud property retrievals. This allows evaluation, in a statistical sense, of the CRM's representation of cirrus cloud physics. Note that SCM results cannot be directly compared to Mace's retrievals because the retrieval criteria must be applied locally, not on the scale of GCM grid cell. However, SCM results can be compared to CRM results (when horizontally averaged). Thus, CRM simulations can be used to link observations and SCMs.

3.3.2 Cloud fraction profiles: Simulated Compared to Observed

We have also run the NCEP SCM (after porting it to our local computers) for the Summer 1997 SCM IOP. Figure 2 compares the cloud fraction profiles for the entire IOP as observed by the MMCR, simulated by the UCLA-CSU CRM, and simulated by the NCEP SCM. We are just beginning our analysis of the NCEP SCM's cloud parameterization. Our plans for Year 2 of this grant are described in "Expected Accomplishments under One-Year Renewal."

3.3.3 Interactions of Deep Cumulus Convection and the Boundary Layer over the Southern Great Plains

We are using observations and cloud-resolving model simulations to better understand the interaction between deep cumulus convection and the boundary layer over the southern Great Plains of the United States. The observations are from a 29-day ARM SCM IOP that took place at the ARM SGP site during June and July 1997. See Krueger et al. (2000) for more details.

The cumulus effects in the boundary layer are due to rain evaporation and fluxes due to cumulus updrafts and downdrafts. We can (in principle) estimate the cumulus effects in the boundary layer using ARM observations obtained during SCM IOPs.

The ARM variational analysis provides Q_1 (the large-scale heat source due to sub-grid scale processes) and Q_2 (the large-scale water vapor sink due to sub-grid scale processes). In addition, we have observational estimates of Q_R (the large-scale radiative heating rate), the surface fluxes of sensible and latent heat due to turbulence, and the boundary layer depth. The CRM simulations can be analyzed analogously.

It has been to difficult to obtain useful results from (**??**) and (**??**) using the available ARM observations, due problems with representing the vertical structure of the boundary layer in the ARM variational analysis and to uncertainties in the available estimates of the boundary layer depth (915 MHz profiler at three sites, an algorithm applied to 3-hourly radiosonde profiles at CF, and visual inspection 3-hourly radiosonde profiles at CF). The observational estimates of the boundary layer depth along with those from two CRM simulations are shown in Figs. 3 and 4.

Our immediate plans are to analyze the CRM simulations and to compare these to analyses of analogs of the SGP observations based on CRM results.

References

Krueger, S.K., G.T. McLean, and Q. Fu, 1995: Numerical simulation of the stratus-to-cumulus transition in the subtropical marine boundary layer. Part I: Boundary-layer structure. *J. Atmos. Sci.,* **52,** 2839–2850.

Mace, G.G., E.E. Clothiaux, and T.P. Ackerman, 2000: The Composite Characteristics of Cirrus Clouds; Bulk Properties Revealed by One Year of Continuous Cloud Radar Data. *J. Climate,* submitted October 1999.

Xu, K.-M., and D. A. Randall, 1996: A semiempirical cloudiness parameterization for use in climate models. *J. Atmos. Sci.*, **53,** 3084–3102.

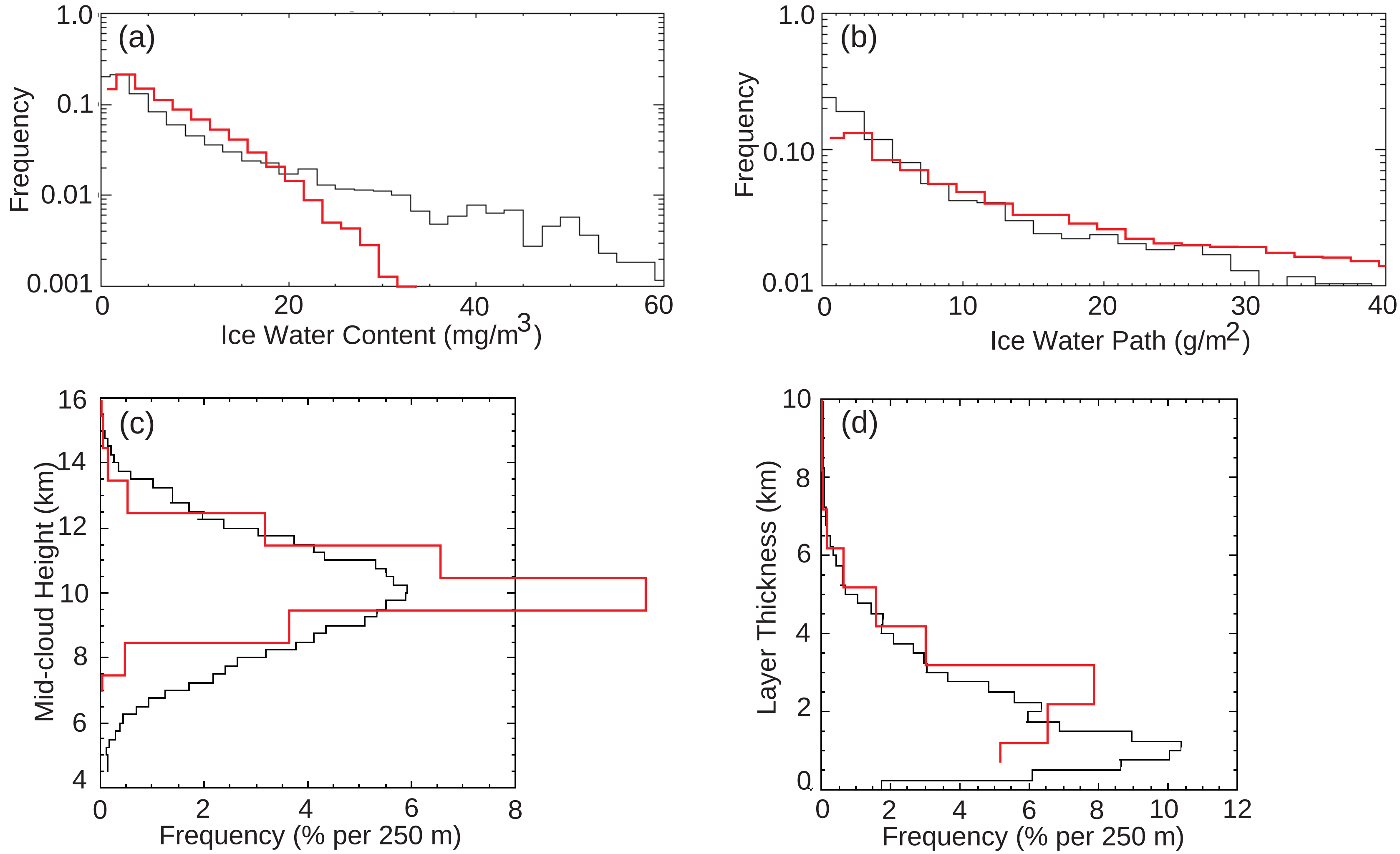
4 Figures

Figure 1 Comparison of simulated and observed cirrus statistics at the ARM SGP site. Red: From a UCLA-CSU CRM simulation of a 29-day period (19 June to 17 July 1997). Black: From Mace et al. (2000) based on one year (Dec. 1996 to Nov. 1997) of MMCR measurements. (a) Frequency distribution of layer-mean IWC for thin cirrus clouds. (b) Frequency distribution of IWP for thin cirrus clouds. (c) Frequency distribution of mid-cloud height for for thin cirrus clouds (CRM) and for all cirrus clouds (Mace et al.). (d) Frequency distribution of cirrus thickness for thin cirrus clouds (CRM) and for all cirrus clouds (Mace et al.).

Figure 2 Time-height cloud fraction at ARM SGP, 19 June to 17 July 1997, surface to 16 km: (top panel) observed by MMCR (3-hour averages), (middle panel) simulated by UCLA-CSU CRM (1-hour averages), and (bottom panel) simulated by NCEP SCM (3-hour averages). Color indicates cloud fraction, which ranges from 0 (violet) to 1 (red).

Figure 3 Boundary layer depths from the CRM simulations and observations for the first half of the summer 1997 SCM IOP. Both (a) and (b) show the boundary layer depths obtained from CRM simulations with interactive radiative heating (solid black line) and prescribed radiative heating (dashed black line) Also shown in (a) are the boundary layer depths estimated observationally at CF by the 915 MHz profiler (blue line), and the Heffter algorithm (green line); and in (b), the 915 MHz profiler at CF (blue +), Beaumont (red +), and Medicine Lodge (green +).

Figure 4 Same as Fig. 3 except for the last half of the summer 1997 SCM IOP.



(a)
Frequency
1.0
0.1
0.01
0.001
0
20
40
60
Ice Water Content (mg/m3)
(b)
Frequency
1.0
0.10
0.01
0
10
20
30
40
Ice Water Path (g/m2)
(c)
Mid-cloud Height (km)
16
14
12
10
8
6
4
0
2
4
6
8
Frequency (% per 250 m)
(d)
Layer Thickness (km)
10
8
6
4
2
0
0
2
4
6
8
10
12
Frequency (% per 250 m)

Figure 1

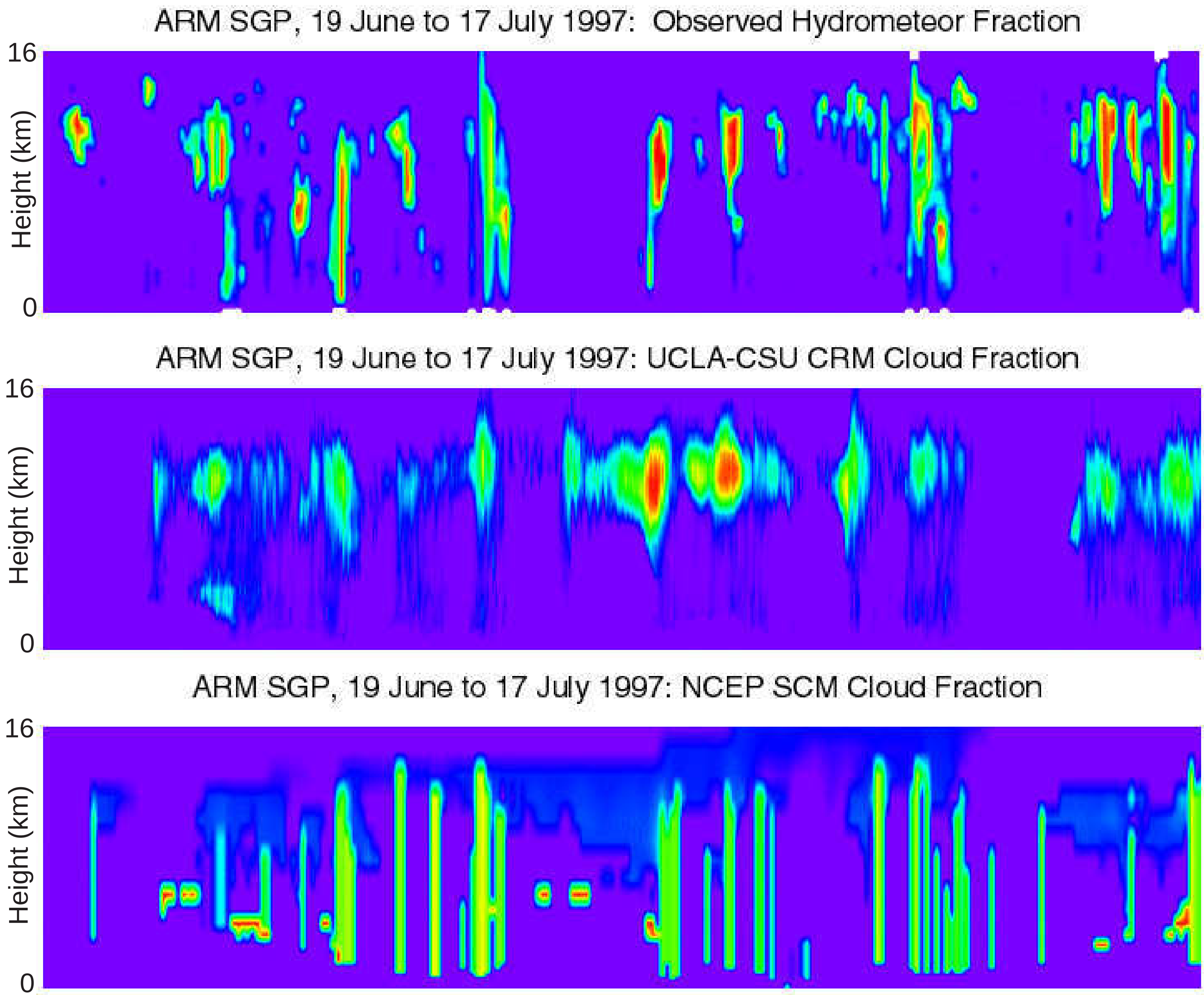

ARM SGP, 19 June to 17 July 1997: Observed Hydrometeor Fraction
16
Height (km)
0
ARM SGP, 19 June to 17 July 1997: UCLA-CSU CRM Cloud Fraction
16
Height (km)
0
ARM SGP, 19 June to 17 July 1997: NCEP SCM Cloud Fraction
16
Height (km)
0

Figure 2

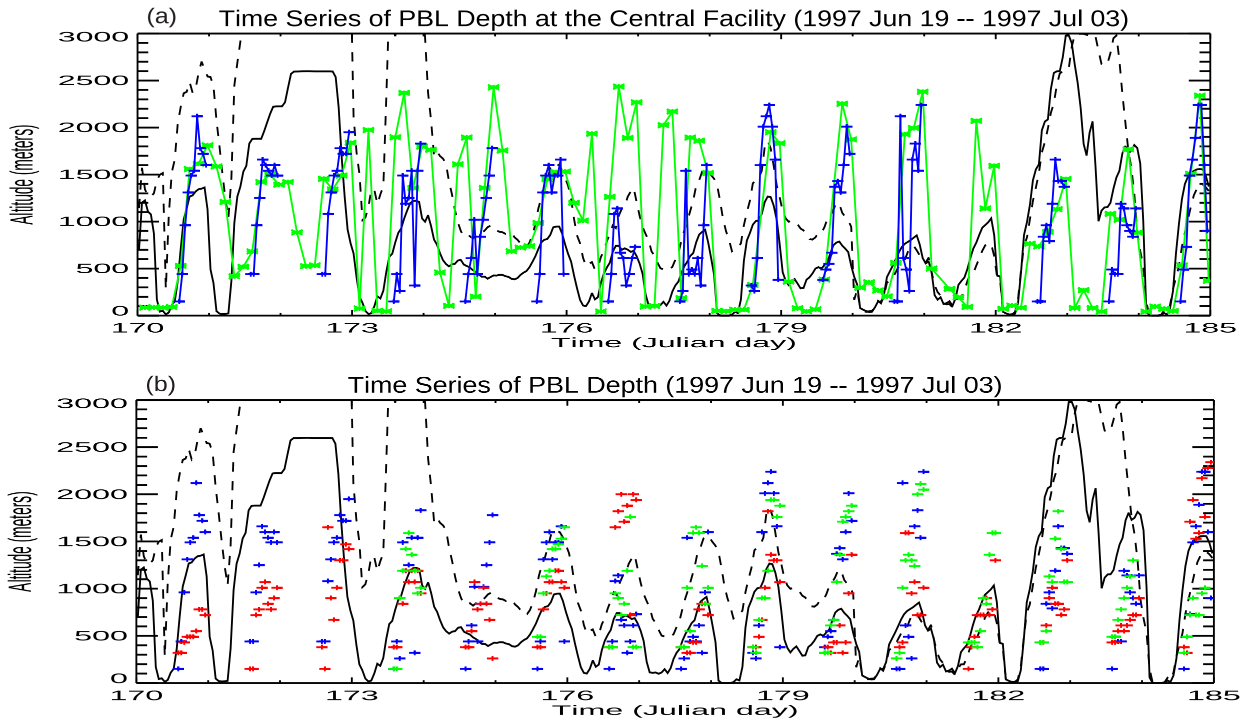


Figure 3: Boundary layer depths from the CRM simulations and observations for the Ørst half of the summer 1997 SCM IOP. Both (a) and (b) show the boundary layer depths obtained from CRM simulations with interactive radiative heating (solid black line) and prescribed radiative heating (dashed black line) Also shown in (a) are the boundary layer depths estimated observationally at CF by the 915 MHz proØler (blue line), and the HeÆter algorithm (green line); and in (b), the 915 MHz proØler at CF (blue +), Beaumont (red +), and Medicine Lodge (green +).

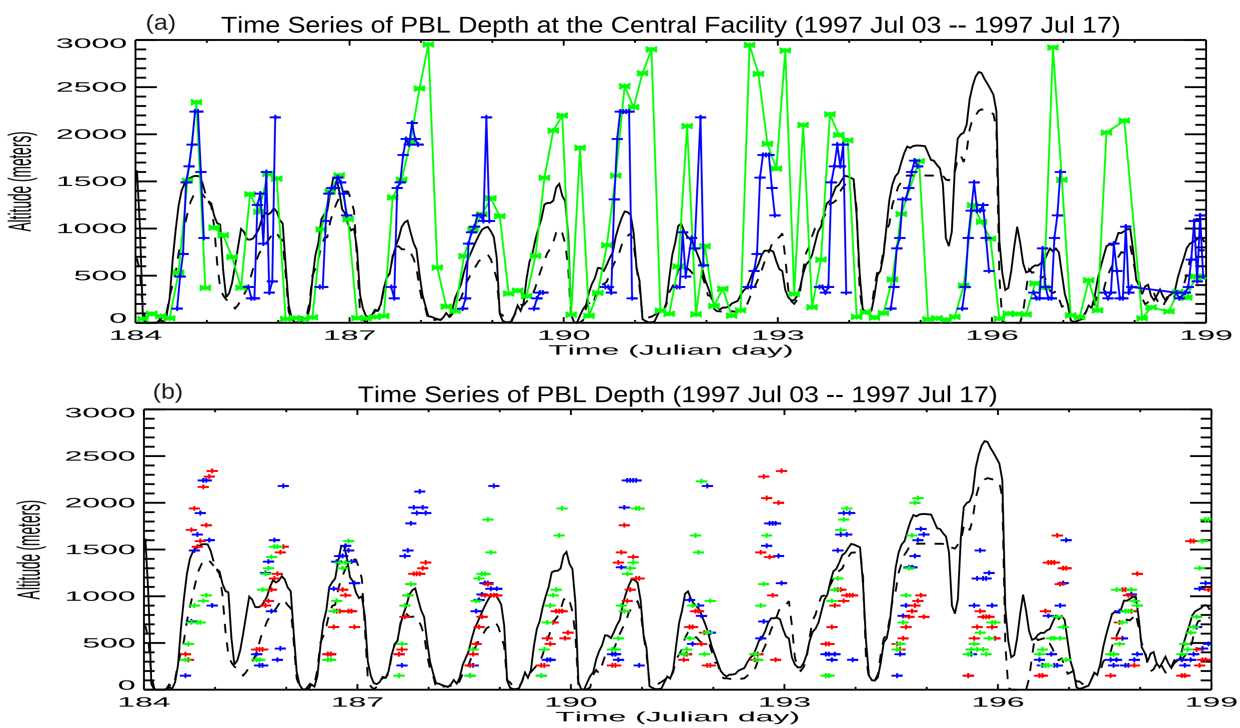


Figure 4: Same as Fig. 3 except for the last half of the summer 1997 SCM IOP.

5 Figures for Presentation

Comparison of simulated and observed cirrus statistics at the ARM SGP site

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Caption:

Red: From a UCLA-CSU CRM simulation of a 29-day period (19 June to 17 July 1997).
Black: From Mace et al. (2000) based on one year (Dec. 1996 to Nov. 1997) of MMCR measurements.
(a) Frequency distribution of layer-mean IWC (ice water content) for thin cirrus clouds.
(b) Frequency distribution of IWP (ice water path) for thin cirrus clouds.
(c) Frequency distribution of mid-cloud height for for thin cirrus clouds (CRM) and for all cirrus clouds (Mace et al.).
(d) Frequency distribution of cirrus thickness for thin cirrus clouds (CRM) and for all cirrus clouds (Mace et al.).

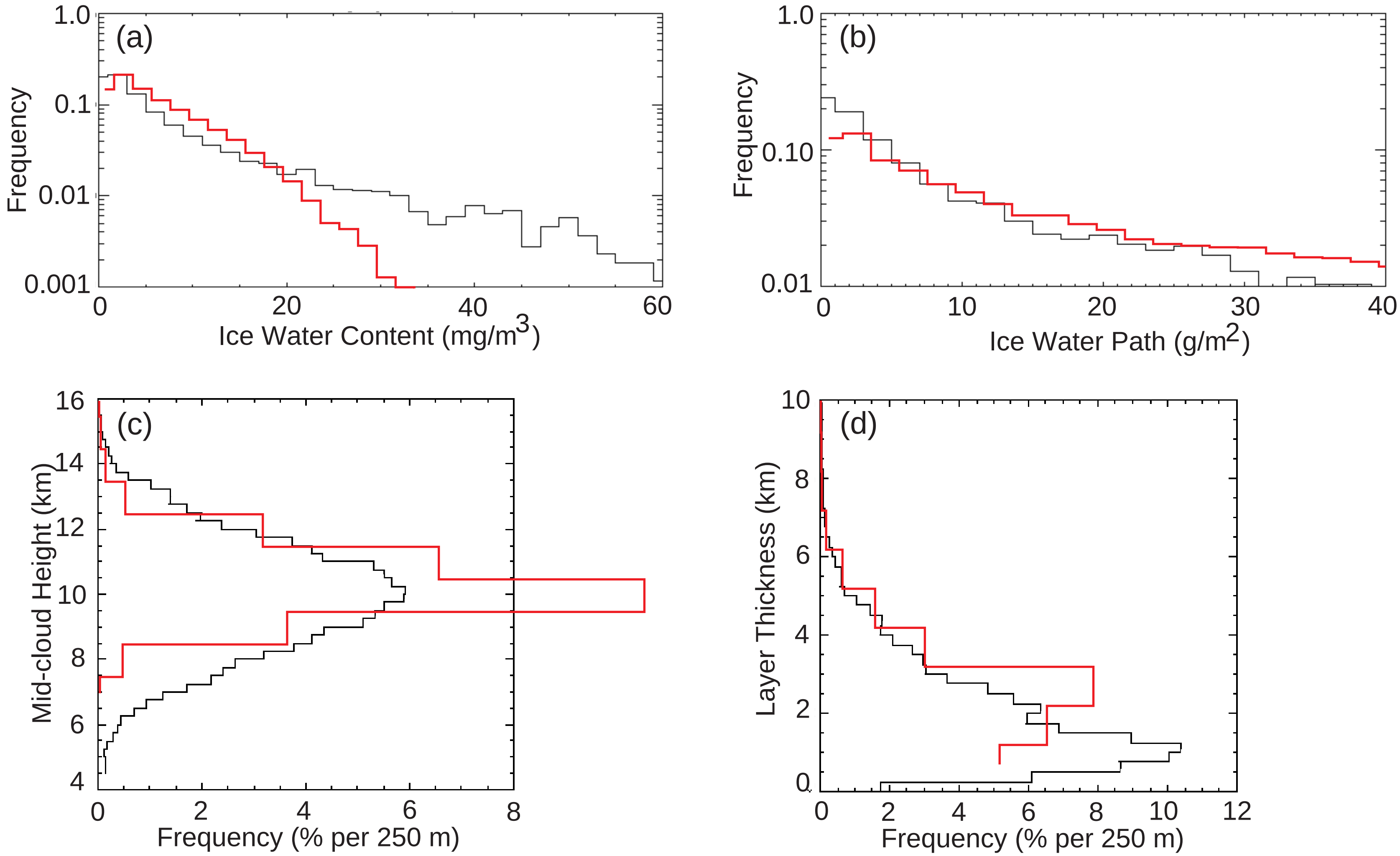
Discussion:

Mace et al. (2000) used cloud radar and IR spectral radiometer measurements to retrieve 3-minute-averaged thin cirrus microphysical properties (IWC, IWP) over the ARM SGP site when there were no lower clouds. Mace et al. also used the cloud radar reflecitivity alone to determine the mid-cloud height and cloud thickness for all cirrus clouds observed. We sampled the CRM simulation at 8 grid columns (64 km apart) every 5 minutes using Mace's thin cirrus criteria.

This figure demonstrates that CRM results can be sampled in a way that allows direct comparison to Mace's thin cirrus microphysical property retrievals. This allows evaluation, in a statistical sense, of the CRM's representation of cirrus cloud physics. Note that SCM microphysical properties cannot be directly compared to Mace's retrievals because the retrieval criteria must be applied locally, not on the scale of a GCM grid cell. However, SCM results can be compared to CRM results (when horizontally averaged). Thus, CRM simulations can be used to link observations and SCMs.

Reference

Mace, G.G., E.E. Clothiaux, and T.P. Ackerman, 2000: The Composite Characteristics of Cirrus Clouds; Bulk Properties Revealed by One Year of Continuous Cloud Radar Data. *J. Climate,* submitted October 1999.



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Frequency (% per 250 m)
(d)
Layer Thickness (km)
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8
6
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Frequency (% per 250 m)

Cloud fraction profiles: Simulated compared to observed

Steven K. Krueger, University of Utah, 2000

Caption:

Time-height cloud fraction at ARM SGP, 19 June to 17 July 1997, surface to 16 km: (top panel) observed by MMCR (3-hour averages), (middle panel) simulated by UCLA-CSU CRM (1-hour averages), and (bottom panel) simulated by NCEP SCM (3-hour averages). Color indicates cloud fraction, which ranges from 0 (violet) to 1 (red).

Discussion:

This figure compares the cloud fraction profiles for 29 days as observed by the MMCR, simulated by the UCLA-CSU CRM, and simulated by the NCEP SCM.

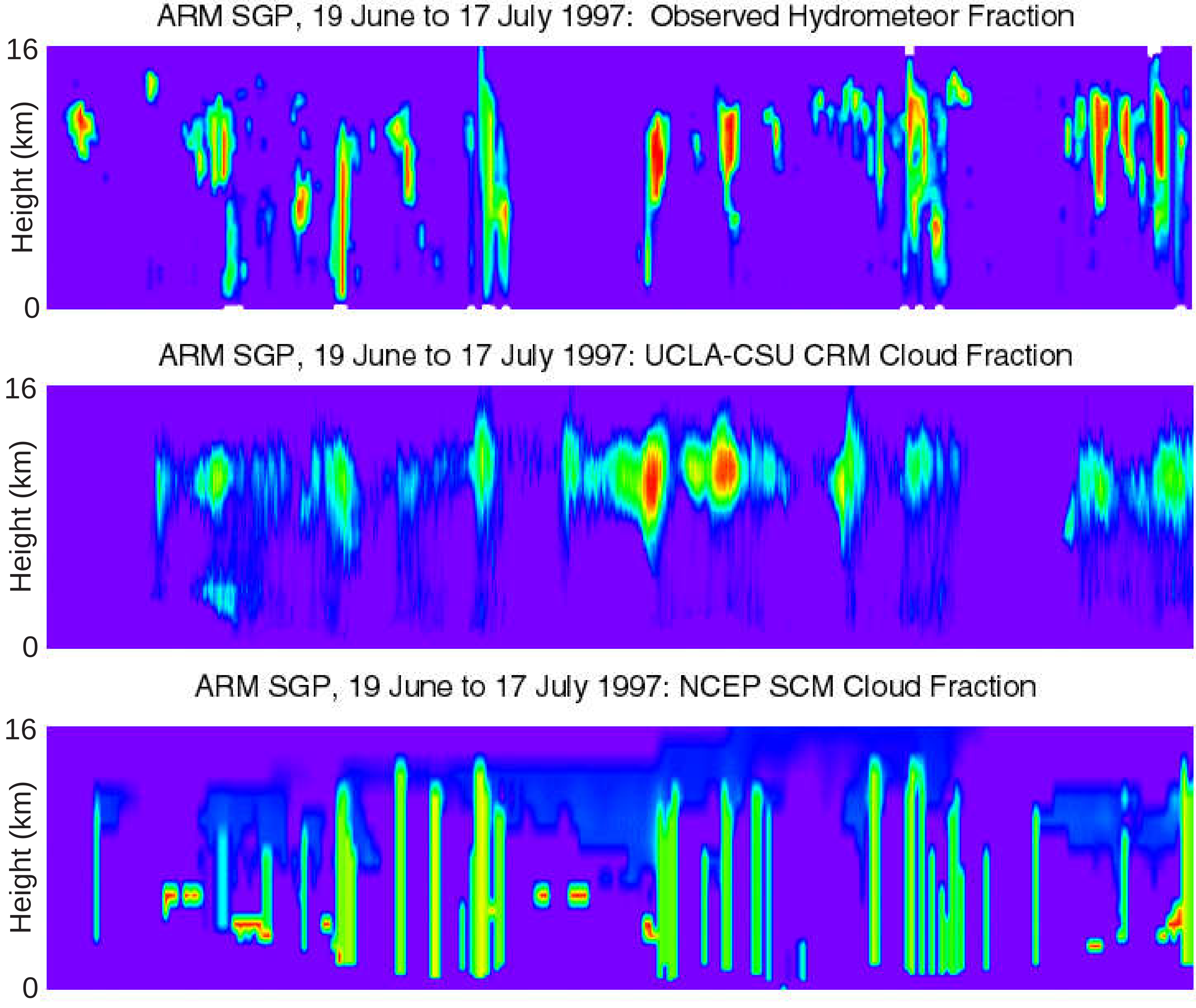
Barnett et al. (1998) found that a 3-hour time average of solar radiation (with diurnal cycle removed) on cloudy days at a single point has a correlation of 0.6 with the average over a region of radius 90 km. Thus, even with a perfect model and 3-hour time averaging, we cannot expect perfect correlation of the simulated cloud fraction over the large-scale CRM/SCM domain (radius 150 km) with the cloud fraction observed by the cloud radar (a point measurement).

Given the above limitation on the expected agreement on short time scales, the CRM cloud fraction is in good agreement with the observed, except on the first day, and around the middle of the simulation when a clear period was observed. A plausible explanation for these difference is that specifying the large-scale advective tendency of condensate to be zero in the CRM simulation (due to lack of observations) does not allow clouds that formed outside the domain to move in, or clouds that formed inside the domain to move out.

There are significant differences between the NCEP SCM and observed cloud fraction profiles, most notably in the SCM's underestimate of cloud fraction at high levels. The NCEP SCM diagnoses stratiform cloud fraction according to the relative humidity, and the convective cloud fraction according to the intensity of the convection. The total cloud fraction equals the convective cloud fraction if present; otherwise, it equals the stratiform cloud fraction.

Reference

Barnett, T. P., J. Ritchie, J. Foat, and G. Stokes, 1998: On space-time scales of the surface solar radiation field. *J. Climate,* **11,** 88-96.


ARM SGP, 19 June to 17 July 1997: Observed Hydrometeor Fraction
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Height (km)
ARM SGP, 19 June to 17 July 1997: NCEP SCM Cloud Fraction
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Height (km)

6 Refereed Publications Submitted or Published during Current Grant Period

* indicates reprint mailed.

Bretherton, C. S., S. K. Krueger, M. C. Wyant, P. Bechtold, E. van Meijgaard, B. Stevens, and J. Teixeira, 1999: A GCSS boundary layer model intercomparison study of the first ASTEX Lagrangian experiment. *Bound.-Layer Meteor.,* **93,** 341–380. (This does not acknowledge ARM support, although it should.)

* Fu, Q., M. Cribb, H. Barker, S. K. Krueger, and A. Grossman, 2000: Cloud geometry effects on atmospheric solar absorption. *J. Atmos. Sci.,* **57,** 1156-1168.

* Lazarus, S. M., S.K. Krueger, and G. G. Mace, 2000: A cloud climatology of the Southern Great Plains ARM CART. *J. Climate,* **13,** 1762–1775.

* Ghan, S. J., D. Randall, K.-M. Xu, R. Cederwall, D. Cripe, J. Hack, S. Iacobellis, S. Klein, S. Krueger, U. Lohmann, J. Pedretti, A. Robock, L. Rotstayn, R. Somerville, G. Stenchikov, Y. Sud, G. Walker, S. Xie, J. Yio, and M. Zhang, 2000: A comparison of single column model simulations of summertime midlatitude continental convection. *J. Geophys. Res.,* **105** (D2), 2091–2124.

7 Extended Abstracts Published during Current Grant Period

* indicates reprint mailed.

Cederwall, R. T., Krueger, S.K., Randall, D.A., Xie, S.C., Xu, K.M., Zhang, M.H., and Yio, J., 2000: The ARM-GCSS SCM and CRM Intercomparison: Preliminary SCM Results. *Proceedings of the Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting,* San Antonio, Texas, DOE. To be submitted.

Krueger, S. K., S. M. Lazarus, Y. Luo, and K.-M. Xu, 2000: Interactions of Cumulus Convection and the Boundary Layer over the Southern Great Plains. *Proceedings of the Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting,* San Antonio, Texas, DOE. To be submitted. (Identical to preprint for 14th Symposium on Boundary Layers and Turbulence.)

Lazarus, S. M., Krueger, S. K., and Frisch, A. S., 2000: Evaluation of a Cloud Fraction Parameterization Using Observations and Model Data. *Proceedings of the Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting,* San Antonio, Texas, DOE. To be submitted.

* Xu, K.-M., S. K. Krueger, L. J. Donner, F. Guichard, W. Grabowski, D. E. Johnson, M. Khairoutdinov, J. C. Petch, D. A. Randall, C. J. Seman, W.-K. Tao, R. T. Cederwall, S. Xie, J. Yio, and M.-H. Zhang, 2000: Cloud-resolving Model Intercomparison with the ARM July 1997 IOP Data. *Proceedings of the Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting,* San Antonio, Texas, DOE. To be submitted. Nearly final version available from:
ftp://ftp.met.utah.edu/pub/skrueger/kmxu-arm2000-ext-abs.pdf

* Krueger, S. K., S. M. Lazarus, Y. Luo, and K.-M. Xu, 2000: Interactions of deep cumulus convection and the boundary layer over the Southern Great Plains. *Preprints, 14th*

Symposium on Boundary Layers and Turbulence, Aspen, CO, Amer. Meteor. Soc., in press.

Krueger, S. K., S. M. Lazarus, Y. Luo, and K.-M. Xu, 2000: Interactions of deep cumulus convection and the boundary layer over the Southern Great Plains. *Proceedings, 13th International Conference on Clouds and Precipitation,* Reno, Nevada, in press. (Identical to preprint for 14th Symposium on Boundary Layers and Turbulence.)

8 Status of Refereed Publications listed as Submitted in Previous Progress Report

Bretherton, C. S., S. K. Krueger, M. C. Wyant, P. Bechtold, E. van Meijgaard, B. Stevens, and J. Teixeira, 1999: A GCSS boundary layer model intercomparison study of the first ASTEX Lagrangian experiment. *Bound.-Layer Meteor.,* **93,** 341–380.

Fu, Q., M. Cribb, H. Barker, S. K. Krueger, and A. Grossman, 2000: Cloud geometry effects on atmospheric solar absorption. *J. Atmos. Sci.,* **57,** 1156-1168.

Ghan, S. J., D. Randall, K.-M. Xu, R. Cederwall, D. Cripe, J. Hack, S. Iacobellis, S. Klein, S. Krueger, U. Lohmann, J. Pedretti, A. Robock, L. Rotstayn, R. Somerville, G. Stenchikov, Y. Sud, G. Walker, S. Xie, J. Yio, and M. Zhang, 2000: A comparison of single column model simulations of summertime midlatitude continental convection. *J. Geophys. Res.,* **105** (D2), 2091–2124.

Krueger, S. K., 2000: Cloud system modeling. *General Circulation Model Development,* D. A. Randall, ed., Academic Press, San Diego, (in press).

Lazarus, S. M., S.K. Krueger, and G. G. Mace, 2000: A cloud climatology of the Southern Great Plains ARM CART. *J. Climate,* **13,** 1762–1775.

Expected Accomplishments under One-Year Renewal

Briefly, we will thoroughly evaluate several aspects of the next generation NCEP global model cloud parameterization.

NCEP's global model has used a diagnostic cloudiness scheme for many years. This is now being replaced by a prognostic cloud water scheme that was implemented in NCEP's regional model several years ago. A prognostic cloud water scheme adds cloud water/ice to the model's prognostic variables. Such a scheme calculates the local time-rate-of-change of cloud water/ice due to the combined effects of condensation/deposition, evaporation/sublimation, conversion to precipitation, turbulent transport, and large-scale advection.

However, the macroscopic distribution of cloud (i.e., the cloud fraction) must still be parameterized. NCEP is testing a cloud fraction parameterization similar to the Xu-Randall parameterization that we have been testing. Such a parameterization uses cloud water/ice as well as relative humidity to diagnose the cloud fraction.

The remaining requirement of a cloud parameterization is to specify the microscopic distribution of water (which combined with the mass of water in a cloud and its macroscopic distribution determine its radiative properties): the phase and size distribution of the cloud particles.

ARM's measurements and retrievals provide the best available data sets for testing the various aspects of such a cloud parameterization.

For example, due to the cloud fraction parameterization's dependence on cloud water/ice content, it cannot be directly tested against observations unless retrievals of cloud water/ice content profiles are available. Currently, only a cloud radar combined with a microwave radiometer or an IR radiometer (i.e., AERI) can provide this information on a continuous basis. And the ARM sites are the only places where such combinations of measurements are made continuously.

Various combinations of ARM remote sensors can also determine the effective cloud particle size.

The catch in using the ARM cloud property retrievals to direcly test large-scale cloud parameterizations is that cloud properties other than cloud fraction profiles cannot be measured continuously; they can only be retrieved under certain conditions. This makes it difficult to estimate the *large-scale* (or time-averaged) cloud properties from the retrievals.

One way around this is to use a CRM as a bridge between the local cloud observations/retrievals and the large-scale cloud properties needed to test cloud parameterizations. A CRM can be sampled at a point under the same conditions that a retrieval is able to made, as well as everywhere under all conditions to provide large-scale cloud properties. By using the retrievals, the CRM-simulated retrievals, and the CRM large-scale properties, one may make more use of the observations that would be possible without the CRM results, and vice versa.

Year 2 Plan

1. Compare the predictions by NCEP global models of clouds and their radiative impacts at the ARM sites (SGP, NSA, and TWP) to observations for several months.

2. Use UU CRM results to examine specific aspects of the NCEP cloud and convection parameterizations.

3. Make changes/improvements to the NCEP cloud and convection parameterizations based on evaluations using ARM measurements and results from the UU CRM.

4. Test the modified parameterizations in the NCEP SCM and in the NCEP global NWP model.